# Making Decisions in Complex Landscapes: Headwater Stream Management Across Multiple Federal Agencies

Case Studies from Two Structured Decision Making Workshops:

1. Potomac Watershed Workshop: February 3-7, 2014 at the National Conservation Training Center, Shepherdstown, WV, USA

2. Merrimack Watershed Workshop: March 3-6, 2014 at the SO Conte Anadromous Fish Laboratory, Turners Falls, MA, USA

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#### **Decision Problem**

Headwater stream ecosystems are vulnerable to numerous threats associated with climate and land use change. In the northeastern US, many headwater stream species (e.g., brook trout and stream salamanders) are of special conservation concern and may be vulnerable to climate change influences, such as changes in stream temperature and streamflow. Federal land management agencies (e.g., US Fish and Wildlife Service, National Park Service, USDA Forest Service, Bureau of Land Management and Department of Defense) are required to adopt policies that respond to climate change and may have longer-term institutional support to enforce such policies compared to state, local, non-governmental, or private land managers. However, federal agencies largely make management decisions in regards to headwater stream ecosystems independently. This fragmentation of management resources and responsibilities across the landscape may significantly impede the efficiency and effectiveness of conservation actions, and higher degrees of collaboration may be required to achieve conservation goals. This project seeks to provide an example of cooperative landscape decision-making to address the conservation of headwater stream ecosystems. We identified shared and contrasting objectives of each federal

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agency and potential collaboration opportunities that may increase efficient and effective management of headwater stream ecosystems in two northeastern US watersheds. These workshops provided useful insights into the adaptive capacity of federal institutions to address threats to headwater stream ecosystems. Our ultimate goal is to provide a decision-making framework and analysis that addresses large-scale conservation threats across multiple stakeholders, as a demonstration of cooperative landscape conservation for aquatic ecosystems. Additionally, we aim to provide new scientific knowledge and a regional perspective to resource managers to help inform local management decisions.

## **Background**

# Legal, regulatory, and political context

Decisions related to headwater stream management are conducted by agencies in concordance with their respective legal mandates and internal policies. The Endangered Species Act (1973) obligates all agencies and other stakeholders to conserve and restore federally listed species and the ecosystems on which they rely, and to consult with US Fish and Wildlife Service or the National Marine Fisheries Service on actions than may affect those species. The Clean Water Act (1972) was designed to protect the chemical, physical, and biological integrity of waters of the US. Depending on their location and other characteristics, these protected waters can include ephemeral, intermittent, and perennial headwaters streams. Additionally, the National Park Service Organic Act (1916) obligates the preservation of all National Park resources to provide public enjoyment of these resources in a manner that will leave them unimpaired for future generations. The National Forest Management Act (1976) and Multiple-Use Sustainable Yield Act (1960) call for the management of renewable resources, sustainable harvest, and multiple uses of the National Forest System through the development and implementation of Forest Plans. The National Wildlife Refuge System Administration Act (1966) requires that various uses of refuge lands must be compatible with the original established purpose of each refuge, and National Wildlife Refuge System Improvement Act (1997) provides additional guidance for the Refuge System to be managed as a national system. Lastly, the National Environmental Policy Act (1969) requires social and economic impact assessments of many federal management activities. Meeting the requirements associated with each of these legal obligations simultaneously can be difficult without clearly articulated goals, objectives, monitoring, and management direction.

A significant impediment to making landscape-scale conservation decisions results from the spatial fragmentation of federal agency land management responsibilities. The capacity for individual agencies to manage a given resource may be locally optimal, but inefficient or suboptimal for the conservation of the resource at a larger spatial scale (i.e., the watershed). The regulatory constraints and mandates of each federal agency may lead to different risk tolerances and ranking of local compared to watershed objectives, potentially leading to inefficient and ineffective conservation.

The Department of the Interior is seeking to address these concerns, to better integrate science and management to address climate change and other landscape-scale issues, via the establishment of the Landscape Conservation Cooperatives (DOI Secretarial Order No. 3289). The development of a shared management strategy among federal agency programs may prove

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difficult, especially when objectives are subject to interpretation by local or regional agency representatives. Local resource managers can share common objectives (e.g., maintain populations of a target species or community); however, the values of common objectives can vary widely and some objectives may not be shared at all (e.g., recreational use and enjoyment and sustainable forest practices). These differential values of multiple objectives can confound the ability for agencies to collaboratively manage resources across the landscape.

## Ecological context

Headwater stream ecosystems contribute substantially to biodiversity within river networks (Meyer et al. 2007) and are especially vulnerable to climate change and human land use alteration (Peterson et al. 2013). Recent climate models predict substantial changes in precipitation in the northeastern US, with higher winter and lower summer precipitation (Hayhoe et al. 2007, Huntington et al. 2009, Rawlins et al. 2012), leading to reduced runoff and lower base streamflows, more frequent droughts, and extended low-flow periods in summer (Hayhoe et al. 2007, Huntington 2003). Base streamflows in headwaters are naturally low because of their small drainage area, and populations dependent on these habitats may be especially vulnerable to stream warming and flow reductions caused by changes in temperature and precipitation associated with climate change, as well as with other human impacts that reduce groundwater recharge and base streamflows (Palmer et al. 2002). The combined effects of climate change and landscape alteration could reduce the length and density of small tributaries (Sophocleous 2007, Winter 2007), but also increase perennial stream length in more urbanized catchments (Roy et al. 2009). These effects could result in populations of headwater-dependent species being 'squeezed' between flow reductions in upper stream reaches and warming stream temperatures in lower reaches of the network, resulting in increased species interactions. The degree of "squeezing" may also vary among gradients of urban development. This squeeze is likely to have strong negative effects on individual species that may be equally or differentially valued by resource managers.

These case studies focused on two watersheds (Potomac and Merrimack Watersheds) within the northeastern US (Fig. 1). The Potomac Watershed (37,800 km<sup>2</sup>) occurs in the Appalachian and North Atlantic Landscape Conservation Cooperative (LCC) Regions, while the Merrimack Watershed (5,010 km<sup>2</sup>) is confined to the North Atlantic LCC Region. Using these watersheds as case studies, we aimed to evaluate the opportunities, benefits and costs to collaborative landscape conservation of headwater stream ecosystems. We included a single land manger representative (each was considered a decision maker) from the USDA Forest Service, FWS National Wildlife Refuges, and National Park Service (hereafter referred to as FS, NWR and NP, respectively) to explore potential collaboration opportunities among federal institutions. This selection process resulted in the inclusion of a National Park located outside of the Merrimack Watershed and a Refuge that occurred on the Potomac Watershed boundary. Federal land holdings varied in size, with FS owning the largest land area within a watershed and NWR holding the smallest. In both watersheds, federal agency land holdings occurred in different regions of the stream network. For example, FS and NPS land holdings in the Potomac Watershed were limited to high elevation areas that contained mostly headwater streams and few larger streams. In contrast, FS lands occurred at high elevations in the Merrimack Watershed and NWR lands occurred at lower elevations. This variation in spatial configuration of federal lands played an important role in framing the decision problem and the development of alternative

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collaborative management strategies. As a result of spatial fragmentation of federal lands, agencies identified additional stakeholders (other federal programs, state land managers, and non-governmental agencies) that may be imperative to include later in the decision processes.

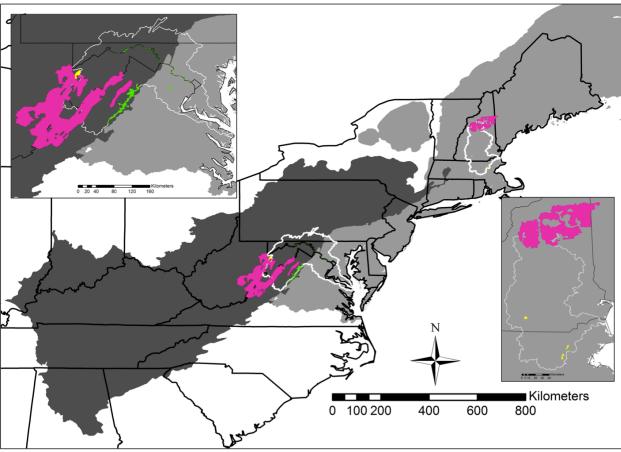


Figure 1. Potomac and Merrimack Watersheds (left and right inserts, respectively; white outline) located within the Appalachian and Atlantic LCC regions (dark and light grey, respectively). NWR (yellow), FS (pink), and NP (green) land holdings are indicated within each watershed.

#### **Decision Structure**

We applied a formal, structured process for decision making, which is comprised of five interrelated components, addressed in succession, and driven by values-based objectives (Hammond et al. 1999, Gregory and Long 2009). Objectives reflect the concerns and values of stakeholders, which can represent a single person or entity, or a consortium of parties responsible for implementing a decision. The process is value-driven because it includes an explicit articulation of objectives of each stakeholder. The process also decomposes the components of the decision so that each can be carefully considered and analyzed. In this way, impediments to decision making from complexity or uncertainty can be explicitly included and addressed. The components of a structured decision making process (PrOACT) include:

1. Define the decision **Problem**(i.e., identify what triggered the problem, the stakeholders and decision maker(s), the legal and regulatory context, and the essential elements of the decision),

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- 2. Identify stakeholder **Objective(s)** and their measureable attributes,
- 3. Develop management Alternative actions hypothesized to influence the objective(s),
- 4. Evaluate the Consequences for each alternative in relation to the objective(s), and
- 5. Analyze the **Trade-offs** among alternatives to identify the preferred decision.

Structured decision-making is an iterative process, with each component being revised to ensure that a satisfactory decision can be made. Developing a *rapid prototype* of the decision simplifies the decision to include the major components (but might not include all possible details) and provides insights and clarity before more resources are allocated to the development of a full-scale decision problem. Additionally, a prototype can be more readily revised and provide a basis for later developments. It is often the case that the prototype serves well as a nearly full-scale solution. During each workshop, we created a 'rapid prototype' of the decision problem by completing two iterations of a 5-part PrOACT process (Fig. 2). In this rapid prototype, decision makers included federal land managers (i.e., NP, NWR, and FS station managers), with guidance from regional federal agency directors that take a larger-scale view of management programs throughout the watershed.

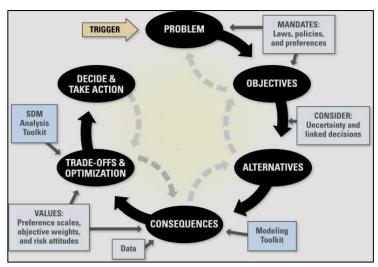


Figure 2. Visualization of the iterative PrOACT process (produced by Jean Cochrane).

#### Decision problem

Framing the decision problem is an imperative and often difficult stage of the decision analysis. During conference calls, stakeholders discussed and revised a proposed problem statement that reflected the scope of the decision. Although this initial framing provided the context for each workshop, we further limited the scope of the decision problem to an ecological threat that was well understood among the decision makers for tractability during the workshops. In the Potomac Watershed, we focused the decision to address threats to cold-headwater streams caused by the loss of the eastern hemlocks (*Tsuga canadensis*). In the Merrimack Watershed, we focused the decision to address the threats to headwater and larger streams from increasing stream temperatures caused by climate change and from increasing land use development.

#### **Objectives**

After framing, the next step in decision analysis is to specify clear and concise management objectives. During this process, stakeholders are encouraged to articulate their concerns and

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consider which objectives are fundamentally important. Fundamental objectives are distinguished from other objectives that are considered means to achieve a fundamental objective. Fundamental objectives are of interest for no other reason except their inherent value. For example, increasing the number of large riparian trees decreases stream temperatures, which is a means to maintain the true fundamental objective of maintaining abundant cold-water dependent stream species. Fundamental objectives can vary in scope and scale and include a variety of goals, such as ecological (e.g., populations, assemblages, ecosystems), economic (e.g., ecosystem services and cost), and political (e.g., public trust and collaboration). Multiple competing objectives are considered simultaneously and refined in the future development of the decision framework.

For each watershed group, we brainstormed potential objectives for each agency (see Appendix A) and then created a list of objectives that were fundamentally important. Both watershed groups agreed that protecting headwater stream species and headwater stream ecosystems were of fundamental importance. Fundamental objectives were generally similar among watersheds and reflected each federal agency's missions and mandates. Nine fundamental objectives were identified among federal agencies in the Potomac Watershed (P) under four themes: ecological, ecosystem service, public use, and cost. Some objectives were relevant to managers at two spatial scales: the local scale of the individual land holding of each station and the broader scale of the watershed. Asterisks denote objectives that were used in the rapid prototype during the workshop due to the time constraint.

- P1. Maximize eastern brook trout persistence (station and watershed scale; ecological),
- P2. Maximize salamander (multispecies) persistence (station and watershed scales; ecological),
- P3. Minimize decline of threatened and endangered headwater species (station and watershed scales; ecological),
- P4. Maximize headwater stream ecosystem integrity (chemical, physical, and biological; station and watershed scales; ecological),\*
- P5. Maintain sustainable forest harvest practices and products (FS station scale only; ecosystem service),
- P6. Maintain water use (ski resorts and local water users; station scale; ecosystem service),\*
- P7. Maximize recreational satisfaction (station scale; public use),\*
- P8. Minimize angler dissatisfaction (station scale; public use),
- P9. Minimize cost (station scale).\*

Eight fundamental objectives were identified among federal agencies in the Merrimack Watershed (M) under four themes: ecological, ecosystem service, public use, and cost.

- M1. Restore and maintain native aquatic assemblages (station and watershed scales; ecological)\*
  - a. In headwater streams
  - b. In riverine streams.
- M2. Minimize invasive species (station and watershed scales; ecological)
  - c. In headwater streams
  - d. In riverine streams,
- M3. Maintain sustainable forest harvest practices and products (FS station scale only; ecosystem service),
- M4. Maintain water use (ski resorts and local water users; station scale; ecosystem service),\*

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- M5. Maximize flood control (station scale and downstream; ecosystem service),\*
- M6. Maximize recreational (non-angling) opportunities (station scale; public use),\*
- M7. Maximize angling opportunities (station scale; public use),\*
- M8. Minimize cost (station scale).\*

Due to the complexity of issues related to the current and future state of each objective, the effects of climate change, multiple competiting objectives, and multiple decision makers, we chose to simplify the scope and complexity of the problem during the workshop. We developed a rapid prototype of the problem using a subset of fundamental objectives (denoted with asterisks above) and an environmental threat that was well understood by the decision makers and scientists present at the workshop. In the Potomac Watershed, we simplified the scope of the problem by focusing on the conservation of cold-water streams only (i.e., "brook trout streams") because a) two stations were located in high elevation areas of the watershed, b) mangers were well informed about the amount and status of cold-water stream habitats, and c) much of the cold-water stream habitats likely occurred across federally protected areas. Additionally, headwater streams are currently threatened by the loss of Hemlock stands from the Hemlock woolly adelgid (an invasive insect) in the Potomac. Thus, we focused on management actions that would mitigate the negative impacts of Hemlock loss on headwater streams over the next 50-years. In the next iteration of this decision problem, we will expand to include climate and land use change threats. For the rapid prototype, measureable attributes were assigned to four objectives in the Potomac Watershed:

- P4. Maximize headwater stream ecosystem integrity: the percent of cold-water stream kilometers with summer temperature not exceeding 21°C and the percent of headwater stream kilometers with adequate riparian buffers,
- P6. Maintain water use: the percent of permitted gallons meeting water quality standards for diverse uses,
- P7. Maximize recreational satisfaction: the percent of users reporting a high quality experience,
- P9. Minimize cost: average annual base funding (dollars) expended for each station.

In the Merrimack Watershed, federally protected areas were not all located in high elevation portions of the watershed and thus did not contain all the cold-water headwater stream habitats. Therefore, a broader definition of headwater streams was used, which included headwater streams and larger water bodies downstream (i.e., riverine habitats) that likely influenced and are influenced by conditions in the headwater ecosystems. In the Merrimack, managers considered management actions that would mitigate the effects of land use development and climate change on headwater streams (not just Helmock loss) over the next 50-years and developed measurable attributes for seven objectives:

- M1. Restore and maintain native aquatic assemblages: stream kilometers with local (headwater or riverine) native assemblage diversity,
- M3. Maintain sustainable forest harvest practices and products: achieving sustainable harvest goals (yes or no),
- M4. Maintain water use: headwater stream kilometers not meeting water quality standards for diverse uses.
- M5. Maximize flood control: minimize the deviation from current maximum flows during high flow events,

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- M6. Maximize non-angling recreational opportunities: the percent of satisfied visitors (using current visitor survey information),
- M7. Maximize angling opportunities: the percent of potential angling opportunities,
- M8. Minimize cost: average annual base funding (dollars) expended for each station.

These attributes were broadly defined and will be further developed in later steps of the decision process. For example, the Potomac Watershed's ecosystem integrity objective was preliminarily represented by a combination of physical, chemical, and biological metrics. Considerable effort is required to identify meaningful attributes of stream integrity that can directly guide the implementation and assessment of alternative management actions, which will be the focus of later workshops. Generally, the value of an objective declines (got worse), as the value of an attribute declines (except for the cost objective in both watersheds and the water use and flood control objectives in the Merrimack Watershed).

We explored the spatial nature of each agency's ecological values to evaluate the capacity of federal institutions to adapt to the ecological threats associated with climate and land use change. Headwater stream habitats and species are influenced by various management activities that occur throughout the watershed landscape (i.e., anadromous fish migrate from the ocean to headwaters for spawning and cold-water stream salamanders depend on dispersal throughout the stream network for persistence). Climate change may reduce the total length and diversity of headwater stream habitats available for species that depend on them. Thus, we explored if federal agencies had the capacity to protect headwater stream ecosystems at the landscape scale if habitats and species shifted off federal lands or if the most effective conservation efforts for these habitats occurred off federally protected lands. In other words, is headwater stream management more effective if 1) federal agencies develop and implement collaborative management plans among their protect lands (e.g., shift resources to federal lands that are of highest priority) or 2) federal agencies collaborated to implement management actions throughout the watershed by focusing on areas of high priority? A priori, we explored the collaborative management of federally protect lands because federal land mangers may be more likely to implement consistent long-term conservation programs for headwater streams compared to private landowners, despite the latter comprising a much greater proportion of the watershed.

To explore the potential for cooperative landscape conservation, we asked each agency to value each ecological objective at two spatial scales: within each station (NP, FS, or NWR) and within the watershed at large (which included all federally protected lands). By comparing station and watershed values and various levels of collaboration among agencies, we can evaluate the perceived effectiveness of conducting cooperative watershed-scale conservation.

For each federal agency, considerable uncertainty in agency-values and perceived policy constraints were identified. For example, is the value of headwater stream ecosystems at the station-level a higher priority than at the watershed-level? Does prioritizing an objective at the station-level limit the ability of agencies to address threats throughout the watershed, and thus negatively influence the station-level objective (e.g., negative feedback loop)? Uncertainty in the current state of the system (i.e., amount of headwater streams with adequate riparian buffer) limited each federal agency from confidently evaluating how important objectives were at both the station and watershed scale.

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#### Alternative actions

After specifying the objectives and measurable attributes, we brainstormed management actions that could affect the fundamental objectives for each watershed. First, each federal agency identified current management actions they implement with a focus on headwater stream ecosystems. Then, agencies identified actions that they could take *if* they collaborated with another federal agency. A range of individual and collaborative management actions were identified (see Appendix B) and then grouped into four portfolios that represented a range of collaborative management. Due to the constraints inherent to rapid-prototyping a decision, we recognized that the variety of management actions within a single portfolio might not be suitable for all agencies. For simplicity, we assumed that all agencies would be able to contribute at some level to each collaboration portfolio. A full suite of potential collaborative actions, including actions "outside the box", were not fully brainstormed in this prototype due to the uncertainty of current policy constraints. We considered a 50-year planning horizon for the successful application of the collaborative management portfolio against projected effects of climate and land use change.

In both watersheds, alternative management portfolios generally represented a gradient from least collaborative (local-scale) management to a shared management plan among agencies throughout the watershed (watershed-scale).

# Potomac Watershed Alternative Management Portfolios (see Appendix B for details):

Alternative 1: Status quo (limited collaboration among federal stations).

This alternative consisted of current management actions and plans for each federal agency and included limited resource sharing (i.e., staff, expertise, and equipment). Alternative 2: Status quo with additional forecasting tools.

This portfolio consisted of new management actions each federal land management agency could take in addition to actions stated in the status quo portfolio, given the availability of shared and new scientific information, such as forecasts of the distribution of hemlocks, stream temperatures, and riparian vegetation.

Alternative 3: Coordinated management actions among federal stations.

This portfolio considered current policy constraints and included more coordinated efforts related to sharing resources for the collaborative management within the three federal lands. Additional potential actions included: utilizing each agency's partnerships, building a common federal agency voice for headwater stream conservation, collecting data to increase the precision of forecasts within each park and throughout the watershed, and sharing station base funds.

Alternative 4: Coordinated management actions among stations and with federal partners throughout the watershed.

This portfolio consisted of all previous portfolio actions and a single federal management strategy shared among stations and includes management opportunities throughout the watershed. Additional potential actions include: collaborating with other federal programs and conducting management actions off federal lands based on the identification of priority areas of high conservation value.

# Merrimack Watershed Alternative Portfolios (see Appendix B for more details):

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Alternative 1: Status quo (limited collaboration among federal stations).

This portfolio consisted of current management actions and plans for each federal agency that also include some collaboration, such as sharing staff, equipment, and expertise.

Alternative 2: Coordinated management actions among federal stations and additional federal programs, focusing on station-specific objectives.

This portfolio considered current policy constraints, and included increased management activities among federal stations such as utilizing each agency's other existing federal programs and partnerships and building a common federal agency voice for the conservation of headwater stream ecosystems.

Alternative 3: Coordinated management actions among federal stations and additional federal programs, focusing on station and watershed objectives.

This portfolio consisted of all previous portfolio actions and additionally included management actions outside of federally protected lands in order to improve the conditions on federal lands and throughout the watershed. Additional potential actions include maintaining ecological connectivity by restoring flows, replacing culverts or barriers, and increasing enforcement of current regulations related to stream buffers ordinances or invasive plant control.

Alternative 4: Coordinated management actions among federal stations, federal programs, and state agencies, with a focus on both station and watershed objectives.

This portfolio included all previous actions and additionally included targeted intensive collaboration with state partners. For example, increasing partnerships with the state would allow for increased management options for trout stocking and harvest regulations outside and within federally protected lands. Additionally, collaborating with local and state agencies can help increase the enforcement of regulations related to stream connectivity, pollution, and invasive species removal.

#### Predictive models

In both watershed groups, we used expert elicitation (i.e., Delphi method; Linstone and M. Turoff 1975) to predict the consequence of alternative action portfolios on each objective's measurable attribute. Local managers, regional representatives and scientists were all considered equal experts in this first rapid prototype of the decision. When available, scientific models and data will replace expert elicitation, but if data proves too scare or inadequate, expert elicitation will be used and include individuals meeting certain criteria set by the stakeholders and decision makers. During the rapid prototype, mangers had sufficient base knowledge of the current state of local resources to preliminarily predict the effects of each alternative management portfolio. We asked each local resource manager (NWR, NPS, and FS) to independently estimate the outcome of each alternative management portfolio on each measureable attribute for their stations respectively. Next, we asked regional representatives (from FWS Region 5 and FS Northeast Region; a NPS regional representative was not available to participate in person for either workshop) and scientists (three individuals in each workshop) to estimate the result of each alternative management portfolio on the measureable attributes of each objective at the watershed-level. After eliciting estimates independently, we allowed discussion and modification of estimates and used an average consequence value across stakeholders for watershed-level objectives (Table 1).

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We acknowledge that additional scientific information concerning the location and state of headwater stream resources will allow increased confidence in the predicted outcome of each portfolio. Future models available for managers and the decision analysis could include: locations of headwater streams throughout each watershed, the identification of unique and shared resources (i.e., trout and salamander populations, as well as hemlock stands), and barriers to stream connectivity such as culverts, roads, or dams. Predictive models related to climate and land use change can also include stream temperature, precipitation, and streamflow models under differing climate scenarios within each station and throughout the watershed.

## **Decision Analysis**

We used a common analytical approach called Simple Multi-Attribute Rating Technique or SMART (Hammond et al. 1999, Goodwin and Wright 2004) to evaluate trade-offs between multiple fundamental objectives under each management. This analysis aimed to identify the optimal decision for *each* federal agency based on the predicted performance of each alternative portfolio, which included objectives at the local and watershed scale for each agency. A multitude of uncertainties were not incorporated into this rapid prototype, but will be included in future iterations of the decision analysis.

## Trade-off analysis

In the rapid prototype, we used swing weighting to investigate the potential trade-offs among four (of nine total) and seven (of eight total) fundamental objectives in Potomac and Merrimack Watersheds, respectively. Swing weighting is a technique that aims to represent decision maker's values in the decision analysis while accounting for the range of potential performances across proposed management actions (Goodwin and Wright 2004). We elicited weights of each objective from each federal land manager, who served as proxies for decision makers that allocate funds to differing management actions. Swing weights reflect how much the decision maker cares about 1) the best future predicted state (magnitude) of the objective under the suite of management alternatives and 2) the change (swing) from the worst to the best future projected state of each objective (evaluated singly). For example, an objective would be assigned a relatively low weight if the measurable attribute were predicted to change little under all alternative management action portfolios or if the decision maker cares little about the future state of the objective relative to the other objectives under consideration. Managers were asked to rank each objective from most to least importance by choosing the objective that they would want to "swing" from worst to best case scenario first, prior to any other objective. Then, managers ranked remaining objectives using the same logic (Table 2). During this swingweighting exercise, there was considerable discussion concerning how each federal land manger interpreted local compared to regional policies, missions, and mandates when ranking station compared to watershed-level ecological objectives.

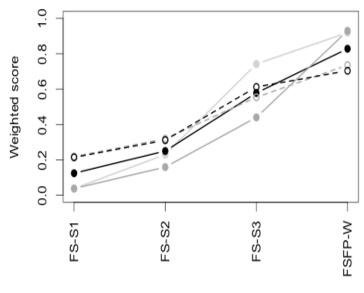
We calculated a weighted score for each alternative collaborative management portfolio, which incorporates the expected outcome of each management portfolio and the relative value (via the weights) of those outcomes, for each stakeholder group (NP, FS, NWR, Region 5 FWS, and scientists; FS Northeast Region was not included due to incomplete weighted scores). The weighted score for each alternative management portfolio is the sum product of the normalized swing weight score and the normalized predicted consequence of each objective. Results

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generally indicated that increased collaboration efforts throughout the watershed were beneficial for each federal agency in both watersheds (Fig. 3 and 4).

In the Potomac Watershed, all alternative management portfolios performed better than the status quo management plan. Specifically, results indicated that all federal stations (including Region 5 FWS, Northeast Region FS, and scientists) would benefit from 1) increased information from threat-forecast models, 2) increased sharing of resources (expertise, equipment, and knowledge), and 3) increased collaboration with other federal partners with the potential for off-station management actions. In the Potomac Watershed, the optimal decision for each federal agency was to collaborate with other stations and off-station federal programs and to increase management activities off-federal lands (Fig. 3). In contrast, federal agencies in the Merrimack Watershed did not benefit by increasing collaboration among stations and with federal programs, but instead benefited greatly when collaboration extended to state agency partners (Fig. 3). The optimal decision for each agency was similar across watersheds, indicating that all agencies would benefit from increased collaboration at both the station and watershed scale under current political constraints and interpretations of mandates of missions of each station.

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Alternative management portfolio

Figure 3. Weighted scores of each alternative management portfolio for the Potomac Watershed indicating the optimal decision (i.e., highest weighted score) for each federal station (NP=light grey solid line; FS=black solid line, NWR=dark grey solid line), FWS Region 5 (grey dotted line), and expert scientists (black dotted line). Alternative portfolios 1, 2, 3, and 4 are represented by FS-S1, FS-S2, FS-S3, FSFP-W, respectively.

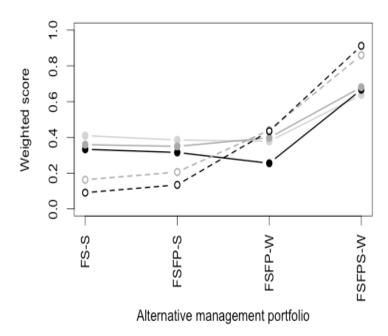


Figure 4. Weighted scores of each alternative management portfolio for the Merrimack Watershed indicating the optimal decision (i.e., highest weighted score) for each federal station (NP=light grey solid line; FS=black solid line, NWR=dark grey solid line), FWS Region 5 (grey dotted line), and expert scientists (black dotted line). Alternative portfolios 1, 2, 3, and 4 are represented by FS-S, FSFP-S, FSFP-W, FSFPS-W, respectively.

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#### Uncertainties

Uncertainty occurs in various stages of the decision analysis, but has not yet been explicitly incorporated into this particular decision problem. During the course of the workshop, we identified several areas where uncertainly may play an important role and warrant further exploration. Linguistic and policy uncertainties can include differential interpretation of local and regional agency mandates and missions as well as political willingness to collaborate (i.e., influenced by high profile species, relationships between agency personnel, or watershed conflicts). System uncertainty can include limited understanding of the current status of headwater stream ecosystems within federal, state, and private lands across the watershed, as well as the consequences of climate or land use change (i.e., extent, location, and time-scale). Environmental uncertainty can include the magnitude and rate of change of increasing temperatures and precipitation caused by climate change. Indeed, all uncertainties may not equally help inform the decision problem of how to collaboratively manage headwater streams in the face of climate change. Future work will continue to identify key uncertainties that may influence the decision problem. Additionally, agencies identified several impediments to watershed-scale collaboration that included (but were not limited to): inadequate resources (time, staff, funding), limited connectivity among federal lands (e.g. noncontiguous positioning of protected lands within the stream network), limited ownership to headwater streams (e.g. any single federal agency may own a small percent of the total headwater streams within the watershed), and increased risk to long-term conservation efforts if priority locations occur on private land.

#### **Discussion**

## *Value of decision structuring*

The participants (agency land managers, regional directors, and scientists) agreed that the process was extremely informative. Although there was considerable discussion of the decision prior to the workshops, the decision problem was nonetheless complex and vaguely defined. The in-person collaboration among federal managers and regional directors was valuable in exploring assumptions regarding policy interpretation, management opportunities, and the values and priorities of each agency. Using this formal decision structure, which is transparent, interactive, and explicit, provided a means for agencies to express concerns and impediments to effective collaborative landscape conservation.

## Landscape Conservation Cooperatives

LCCs are regional partnerships of federal, state, tribal, international, and non-governmental organizations working together to sustain natural and cultural resources in the face of numerous threats associated with global climate change. Since LCCs transcend political and jurisdictional boundaries, transparent and collaborative approaches are necessary for stakeholder participation and effective conservation. Generally, LCCs are governed by a Steering Committee, which appoints and is supported by a Technical Committee. A challenge for many agencies is how to communicate their objectives, given that many agencies have multiple programs with various missions (i.e., FWS's Ecological Services, Fisheries, Migratory Bird Management, and Refuges programs). During the course of these workshops, we generally found support that the value of ecological resources differs among- and within-federal agencies. For example, as the physical

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distance from the federal land management unit increases, the value of headwater stream ecosystem integrity may decrease for local managers (solid black line; Fig. 5). However, a regional agency manager may lack a location-bias in their ecological objective (dotted black line; Fig 5.), and instead value resource where they are of high conservation priority and have a high probability of success.

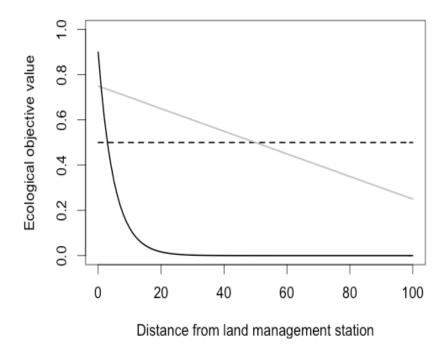


Figure 5. Hypothetical ecological objective values (1 = high value, 0 = low value) for a federal park or refuge manager (black solid line), federal regional director (black dotted line), and local watershed group director (grey solid line) in relation to the distance from a local land management station.

## Prototyping process

Despite conference calls with stakeholders prior to the workshop that aimed to better frame the decision problem, participants were generally concerned about the scope and vulnerability of headwater stream communities (i.e., salamanders and brook trout) to climate change. Thus, we broadened the scope of the problem to encompass a broader range of concerns of managers and will continue working with each agency to define and assess the scale and scope of concerns regarding threats to headwater stream ecosystems.

We gained several insights from both workshops concerning headwater stream management that warrant further exploration. First, federal agency objectives were difficult to define in relation to a desirable state of the system in part because of linguistic uncertainties in agency-specific policies (i.e., "natural" ecosystems, ecosystem integrity, trust species, non-federally listed headwater species). Second, the spatial scale of interest regarding these objectives also varied within and among federal agencies, causing much discussion about the importance of local vs. watershed-scale objectives for conservation. Lastly, federal land managers agreed that in order to achieve effective collaborative management at the watershed-scale, additional stakeholders, such

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as state and non-profit partners, may need to be included in collaborative management decisions and the future development of the decision problem.

Additional workshops are planned to occur over the next couple of years (1 in late 2014 and 2 in 2015) and stakeholder involvement may be widened to include other federal and non-federal agency partners. Objectives, values, and alternative collaborative management actions will be revisited and specific actions will be linked to ecological outcomes. Since the decision process is iterative, its success will depend on the continual participation and feedback of resource managers. We aim to explore the most effective collaborative management strategies within watersheds and evaluate where (which watersheds or LCCs) these strategies may be most successful to address future threats to headwater streams, while addressing a multitude of additional agency needs.

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## **Tables**

Table 1. Consequence table containing the average elicited effect of each alternative management portfolio on measurable attributes for each fundamental objective for the Potomac and Merrimack Watersheds at the end of a 50-year time scale. Objectives occur at two spatial scales, the watershed (W) and each individual federal land managing unit. Potomac Watershed: NPS = Shenandoah National Park, FS = George Washington Forest, NWR = Cannan National Wildlife Refuge. Merrimack Watershed: NPS = Acadia National Park, FS = White Mountain Forest, NWR = Eastern Massachusetts National Wildlife Refuge Complex. Multiple objectives represent potentially competing management actions addressing ecological (ECO), ecosystem service (ES), public use (PU), and cost values.

Potomac Watershed										
				Alternative Management Portfolios						
Fundamental objective	Measurable attribute(s)	Direction	Spatial scale	Status quo	Additional information	Among station collaboration	Watershed collaboration			
	Percent of cold-water stream kilometers with summer temperature <21°C	max	W	70	75	80	85			
EGO			NPS	70	70	71	71			
ECO:			FS	65	67	78	75			
Headwater			NWR	90	90	91	95			
stream	Percent of headwater stream kilometers with adequate riparian buffer	max	W	66	68	69	75			
ecosystem integrity			NPS	99	99	99	99			
			FS	80	81	82	82			
			NWR	70	70	70	75			
PU: Recreation	Percent of users		NPS	75	75	75	76			
satisfaction	reporting a high	max	FS	25	25	35	25			
within stations	quality experience		NWR	90	90	92	95			
EG W	Percent of permitted	max	NPS	100	100	100	100			
ES: Water use within stations	gallons meeting water quality standards		FS	99	98	98	95			
within stations			NWR	100	100	99	95			
C = =4 ===:41=:		min	NPS	15	15	15	30			
Cost within	Base funding (\$K)		FS	150	150	225	225			
each agency	- , ,		NWR	10	10	15	15			

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Table 1. continued.

		Me	rrimack V	Vatershe	d				
					Alternativ	Alternative Action Portfolios			
Fundamental objective	Measurable attribute	Direction	Spatial scale	Status quo	Among station collaboration	Watershed collaboration	Watershed collaboration with state partners		
ECO: Native	Stream kilometers	max	W	2345.0	2378.5	2512.5	2847.5		
aquatic	with local (headwater		NPS	140.4	152.1	152.1	175.5		
assemblages	or riverine) native		FS	2430.0	2430.0	2430.0	2551.5		
	assemblage diversity		NWR	38.4	43.2	57.6	57.6		
ES: Forest products	Achieve sustainable harvest goals	yes=1 no=0	FS	1	1	1	1		
ES: Water use	Headwater stream	min	W	2345.0	2345.0	2010.0	1675.0		
	kilometers not meeting		NPS	19.5	19.5	15.6	13.26		
	water quality		FS	270.0	270.0	162.0	135.0		
	standards for use		NWR	30.0	30.0	24.0	18.0		
ES: Flood	Deviation from current	min	W	1.50	1.45	1.40	1.25		
control	maximum flows		NPS	1.30	1.30	1.20	1.20		
	during high flow		FS	1.40	1.40	1.40	1.30		
	events		NWR	1.40	1.40	1.35	1.25		
PU: Recreation	Percent of satisfied	max	NPS	98	98	98	98		
opportunities	visitors		FS	75	75	75	95		
within stations			NWR	85	85	90	85		
PU: Angling	Percent of potential	max	W	70	70	75	110		
opportunities	angling opportunities		NPS	80	80	85	85		
	-		FS	80	80	85	85		
			NWR	75	80	85	85		
Cost within	Base funding (\$K)	min	NPS	250	260	300	300		
each agency			FS	2500	2600	3000	3000		
- •			NWR	75	90	100	100		

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Table 2. Swing weights determined for each stakeholder group: three federal land management agencies (NPS, FWS, FS), Region 5 FWS, scientists, and overall average from the Potomac and Merrimack Watersheds. The highest swing weight (magnitude and swing) is indicated by a value of 100 (green) and the lowest swing weight is indicated by a value of 0 (red; no value in this decision problem).

Potomac Watershed									
Fundamental	Measurable	Spatial				Swing weight			
<u>objective</u>	attribute(s)	Direction	scale	NPS	FS	NWR	FWS Region 5	Scientists	Average
	Percent of cold-water stream kilometers with summer temperature <21°C	max	W	90	95	100	100	99	97
			NPS	90	90	10	10	40	48
ECO: Headwater			FS	100	100	75	75	98	90
stream ecosystem			NWR	20	95	95	75	86	74
integrity	Percent of headwater stream kilometers with adequate riparian buffer	max	W	100	95	95	100	100	98
			NPS	0	0	0	0	0	0
			FS	90	99	10	25	85	62
			NWR	20	90	100	50	90	70
PU: Recreation	Percent of users reporting a high quality experience	max	NPS	5	10	0	10	1	5
satisfaction			FS	0	15	0	10	50	15
within stations			NWR	0	15	25	10	45	19
	Percent of permitted gallons meeting water quality standards	max	NPS	0	0	0	0	0	0
ES: Water use within stations			FS	10	40	0	50	80	36
			NWR	5	10	10	50	81	31
Cost within each agency	Base funding (\$K)	min	NPS	5	0	0	10	5	4
			FS	0	50	0	10	20	16
			NWR	0	0	10	10	3	5

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Table 2. continued.

Merrimack Watershed									
Fundamental	Measurable		Spatial				Swing weight		
objective	attribute(s)	Direction	scale	NPS	FS	NWR	FWS Region 5	Scientists	Average
ECO: Native	Stream kilometers with	max	$\mathbf{W}$	90	20	100	100	100	82
aquatic	local (headwater or		NPS	90	10	95	75	50	64
assemblages	riverine) native		FS	90	100	95	75	70	86
	assemblage diversity		NWR	90	10	98	75	50	65
ES: Flood control	Deviation from current	min	W	80	10	70	100	40	60
	maximum flows during		NPS	80	0	70	75	30	51
	high flow events		FS	80	30	70	75	30	57
			NWR	80	0	80	75	30	53
ES: Water use	Headwater stream	min	W	95	20	95	100	100	82
	kilometers not meeting		NPS	95	5	85	50	25	52
	water quality standards		FS	95	50	85	75	60	73
	for use		NWR	95	5	90	50	25	53
ES: Forest	Achieve sustainable	yes=1	FS	0	0	0	0	0	0
products	harvest goals	no=0							
PU: Recreation	Percent of satisfied	max	NPS	0	0	0	0	0	0
opportunities	visitors		FS	85	20	75	25	6	42
within stations			NWR	85	0	65	25	2	35
PU: Angling	Percent of potential	max	W	85	0	75	25	4	38
opportunities	angling opportunities		NPS	85	0	65	25	2	35
			FS	85	30	60	25	2	40
			NWR	85	0	75	25	3	38
Cost within each	Base funding (\$K)	min	NPS	75	0	55	10	10	30
agency	- , ,		FS	75	80	55	10	20	48
			NWR	75	0	55	10	12	30

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## Appendix A. List of potential objectives for each watershed

## Potomac Workshop

- 1. Maximize brook trout persistence, occupancy, abundance
- 2. Maximize salamander persistence
- 3. Minimize decline of threatened and endangered headwater species (i.e., macroinvertebrates, snails, mussels, vegetation)
- 4. Maximize headwater stream ecosystem integrity (chemical, physical, and biological aspects)
- 5. Maximize ecosystem services
  - a. Meet Forest Plan harvest and sustainability goals
  - b. Maintain water use (ski resorts and local water users
- 6. Maximize use and enjoyment
  - a. Maximize recreational satisfaction (aesthetics, exercise) and educational opportunities
  - b. Minimize angler dissatisfaction (maintain opportunities and quality of experience)
- 7. Minimize cost

## Merrimack Workshop

- 1. Maintain functioning aquatic ecosystems [includes species, water quality and is the overarching fundamental objective]
  - a. In headwaters
  - b. In rivers
- 2. Maintain native assemblages (maximize proportion of habitats within desired assemblage of invertebrates, fish, salamanders, frogs, turtles, mussels, riparian birds, plants, etc. Native assemblage varies among locations)
  - a. In headwaters
  - b. In rivers
- 3. Minimize invasive species (i.e., carp, crawfish, fish)
- 4. Maximize ecosystem services (i.e., cold, clean and bountiful water also presume necessary for native assemblages, recreation opportunities)
  - a. Maintain water use of ski areas (WMNF)
  - b. Maintain municipal water uses
    - i. surface water supply (Acadia no additional treatment from 5 lakes)
    - ii. groundwater supply (wells near eastern MA)
    - iii. watershed protection major factor in WMNF surface water supply, no additional treatment
  - c. Maximize flood control (i.e., maximize transient storage)
  - d. Maximize forest services
- 5. Maximize recreation opportunities
  - a. Maximize angling opportunities
    - i. In headwaters
    - ii. In rivers

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- b. Maximize paddling (in rivers) opportunities
- c. Maximize aesthetic enjoyment
  - i. In headwaters (hiking and camping access)
  - ii. In rivers
- d. Minimize cost to agencies

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# Appendix B. List of alternative action portfolios with a list of potential management actions.

Potomac Watershed Alternative Management Portfolios (rapid prototype focused on addressing threats to headwater streams from Hemlock loss):

- Alternative 1: Status quo with limited collaboration among stations. This portfolio consisted of current management actions and plans by federal land management agencies. Currently, stations have limited collaboration by sharing resources, such as staff, equipment, and expertise. For each station, managers listed current management actions related to mitigating the loss and potential loss of Hemlocks, as well as actions related to headwater stream management.
- Canaan National Wildlife Refuge: plant riparian vegetation, collaborate with off-refuge beetle releases, monitor Hemlock status, cooperate with working groups on beetle-release experiments and on genetic nursery stocks)
- Shenandoah National Park: collaborate with FS to treat Hemlocks in high elevations and recreational areas, remove dead Hemlocks near recreational areas and roads
- George Washington Forest Service: conduct beetle releases, treat Hemlocks in recreational areas and riparian zones, remove dead Hemlocks near recreational area, allow research on Hemlock removal on headwater stream temperatures, remove dead Hemlocks for use in stream restoration projects as large woody debris, expand forest management into former Hemlock stands, conduct riparian restoration and underplant riparian vegetation.
- Alternative 2: Status Quo with additional information provide by current data sources. This portfolio consisted of new management actions each federal land management agency could take in addition to actions stated in the status quo portfolio, given the availability of new forecasts of the distribution of Hemlocks, continued threat of Hemlock woolly adelgid, stream temperatures, and riparian tree composition in headwaters streams within each station and throughout the Potomac over next 50-yrs. Given the outcomes of such forecasts, each agency listed potentially new management actions.
- Canaan National Wildlife Refuge: conduct more aggressive management to save current hemlocks and more aggressive management to mitigate loss of future hemlocks in riparian areas.
- Shenandoah National Park: conduct riparian restoration in areas previously occupied by Hemlocks.
- George Washington Forest Service: conduct more aggressive underplanting of trees in riparian zones and change location of Hemlock treatments.
- Alternative 3: Coordinated management actions among federal stations. This portfolio considered current jurisdictional constraints, and included more coordinated efforts related to shared research projects, using partnerships, building a common federal agency voice for the conservation of headwater stream ecosystems, and collection of better data to increase the precision of forecasts within each park and throughout the watershed. For example, all agencies could conduct *shared research projects* focusing on the effects of hemlock treatments on stream temperature, ecosystem integrity, and rare salamanders, and on the effects of riparian tree species on stream temperatures and ecosystem integrity. Additionally, experiments could be conducted on other federal lands to help meet the high burden of proof required for National Park Service to adapt particular management

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- actions. Lastly, *collecting better temperature data* within each park and throughout the watershed would better inform the location and intensity of particular management actions within each park (i.e., Hemlock treatments and riparian restoration).
- Alternative 4: Coordinated management actions among stations and throughout the watershed. This portfolio consisted of all previous portfolio actions and a *single federal management strategy* for conserving headwater stream ecosystem integrity *among stations and throughout the watershed*. Potential actions include management off of current federal lands based on the identification of priority areas of high conservation value. For example, Forest Health funds could be reallocated to areas outside of stations and co-management actions could include coordinating funds for riparian restoration and temperature monitoring outside of station boundaries.

Merrimack Watershed Alternative Management Portfolios (rapid prototype focused on addressing threats associated with climate and land use change):

- Alternative 1: Status quo with limited collaboration among stations. This portfolio consisted of current management actions and plans by federal land management agencies. Currently, stations have limited collaboration by sharing resources, such as staff, equipment, and expertise. For each station, managers listed current management actions related to mitigating the loss and potential loss of Hemlocks, as well as actions related to headwater stream management.
- Massachusetts Wildlife Refuge Complex: invasive plant control (water chestnut, purple loosestrife) and training, Hemlock treatments, vegetative habitat restoration near cold water streams, manage and provide equipment to partners, replaced culverts, provide information and support for municipalities to reduce impacts of development on streams, support research projects, work with watershed groups (e.g., OARS) to monitor water quality for wastewater treatment plant effluent, contact regulating authorities if needed, daylighting of headwater streams in Oxbow watershed
- Acadia National Park: monitor aquatic invertebrates and water quality, promote and provide research funds (i.e., acid rain effects, streamflow, biological projects) in NP, replace undersized culverts, conduct invasive species management (purple loosestrife), treat Hemlocks, conduction educational programs on invasives outside the NP, work with state on brown and rainbow trout stocking within the NP.
- White Mountain National Forest: limit stocking of nonnative trout, promote research in NF, provide protocols for sterilization/hygiene to limit spread of didymo and invasives, replace culvers, manage conserve riparian zones using best management pratices, conduct in-stream habitat restoration, promote silviculture in riparian zones, restrict timber harvest on poorly buffered areas near streams, allow state monitoring periodically throughout NF.
- Alternative 2: Coordinated management actions among federal stations. This portfolio considered new management actions that each agency could do if they collaborated with other agencies.
- Massachusetts Wildlife Refuge Complex: inventory of headwater streams and their biological condition, remove invasive fish (i.e., carp), daylight streams.
- Acadia National Park: close and remove roads, promote harvest regulations or create stream-designations for trout harvest, instream restoration (i.e., replace riprap), remove non-native fish, reduce mercury contamination by liming or adding nutrients.

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- White Mountain National Forest: stream-liming experiments and projects, long-term monitoring sites for trout, close and remove roads, reduce mercury contamination by liming or adding nutrients.
- Alternative 3: Coordinated management actions among stations and throughout the watershed. This portfolio consisted of the inclusion of management actions occurring off-federal land stations in order to improve the conditions within stations and throughout the watershed. Examples include maintaining ecological connectivity by restoring flows and replacing culverts or barriers, increased enforcement of current regulations of stream buffers ordinances and invasive plant control, increasing protection of intermittent streams, developing a comprehensive management plan for Maine's coastal streams (harvest of trout and eel), and increase funding of projects outside federal agencies via contracts and cooperative agreements.
- Alternative 4: Coordinated management actions among stations and throughout the watershed, working intensively with state partners. This portfolio included all previous actions and the addition of specific collaboration with state partners in implementing management actions. For example, the state is largely in control of trout stocking and harvest regulations outside and within federal land holdings. Additionally, collaborating with local and state agencies can help increase the enforcement of regulations related to stream connectivity, pollution, and invasive species removal.

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